

Regional Risk Assessment Predictions for the Decline and Future Management of the Cherry Point Herring Stock and Region

*Wayne G. Landis, April J. Markiewicz, Jill F. Thomas and Emily Hart Hayes
Institute of Environmental Toxicology and Chemistry, Huxley College of the
Environment, Western Washington University*

P. Bruce Duncan

United States Environmental Protection Agency, Region 10

Abstract

The Pacific Herring stock that spawns at Cherry Point, west of Bellingham, WA, has undergone a dramatic decline in the past 10 years. We conducted a regional ecological risk assessment using the relative risk model (RRM) to investigate the causes of the current decline, current risks to the population, and the outcomes of future management options. The RRM incorporates geographic location and multiple anthropogenic and natural stressors into estimating risk. In addition to the population decline of the herring, we also see a collapse of the age structure, reduction of recruitment from other populations, and a decrease of the spawning range. The retrospective risk assessment identified overexploitation as the primary risk factor. Warmer sea surface temperatures associated with a warm Pacific Decadal Oscillation have contributed to a lack of recruitment from northern herring populations. Current risk factors to the reduced population center on the destruction of the spawning habitat at Whitehorn Point from spills, development, and natural alterations to the environment. Included in our assessments are testable risk hypotheses and estimates of uncertainty. The relative risk methodology is adaptable to a variety of risk assessment and decision-making processes within the Puget Sound and coastal regions of this state.

Introduction

The Pacific herring stock that spawns at Cherry Point, west of Bellingham, WA, has undergone a dramatic decline in the last 20 years. The Cherry Point region has associated with it two oil refineries and an aluminum smelting operation. Fishing for herring roe and eggs has occurred in the past, but is now banned in the region. Our charge from the Washington State Department of Natural Resources was to evaluate the risk factors to Herring posed by the Cherry Point region in order to manage the site. An additional charge was to evaluate alternative resident endpoints as tools for resource managers for managing the region.

We conducted a regional ecological risk assessment using the relative risk model (RRM) to investigate the causes of the current decline, current risks to the population, and the outcomes of future management options. The RRM incorporates geographic location and multiple anthropogenic and natural stressors into estimating risk. The population decline of the herring, corresponds with a collapse of the age structure, although survivorship of eggs to the Age 2 class has not diminished. The range of spawning areas has also declined, with the area of Point Whitehorn as the principal location.

The retrospective risk assessment identified climate change, as expressed by the warmer sea surface temperatures associated with a warm Pacific Decadal Oscillation (PDO), and exploitation as important risk factors. The warmer water also changes patterns in food resources, predators, and water quality. Contaminants have the potential for impact, but exposure to the eggs, hatchlings and fry has not been demonstrated at Cherry Point. Exposure to contaminants to adults during migration may occur and has been included into our assessment. Modeling of the population age versus fecundity curves and survivorship data indicate that the current population of Age 2 and 3 fish can not be self sustaining without the survivorship or immigration of Age 4 and older fish.

Current risk factors to the reduced population center on the destruction of the spawning habitat at Whitehorn Point from spills, development, and natural alterations to the environment due to the PDO and other climate change factors. Included in our assessments are testable risk hypotheses and estimates of uncertainty.

Since herring are transitory, alternate indicators of the ecological resources need to be developed to effectively manage the Cherry Point region. Eelgrass, Dungeness crab, surf smelt and sand lance, shellfish, blue and Great Blue Heron, are recommended as alternative endpoints to effectively manage the ecological resources in the region.

We make a series of recommendations for future research in the area. These include understanding the loss of older age class fish, determining contaminant loadings in adult fish, the use of alternative endpoints, and preserving the existing habitat as the herring populations increase as the PDO shifts to a cooler period.

The next sections outline the relative risk method for regional risk assessments, summarizes our risk findings, and lists and characterizes our alternative assessment endpoints.

Regional Risk Assessment

The goal of an ecological risk assessment is to assist the decision-making process in the management of ecological systems. To accomplish this goal, the risk assessment should address the specific needs of the decision maker by addressing the relevant geographical area, using endpoints specific to the decision making process, using a method amenable to additional iterations as new information is gathered, and to communicate in a manner that accurately reflects the results including uncertainty. The process that we have developed in order to meet these goals is the Relative Risk Method.

Introduction to the Relative Risk Method (RRM)

The RRM was developed during our ecological risk assessment of Port Valdez, AK. Like this study area, Port Valdez has a variety of anthropogenic stressors including fish hatcheries, fish processing wastes, petroleum-based effluents from the pipelines, municipal effluents and tanker traffic (Landis and Wiegers 1997, Wiegers and others 1998). Natural stressors include the aftermath of the Alaskan Earthquake, sediment deposition from spring glacier melts, and ice scouring of the mudflats. Endpoints were numerous, from protection of wild salmon runs and a population of sea otters, to maintaining water quality.

Source-Habitat-Impact

Assessment methods traditionally evaluate the interaction of three components: stressors released into the environment; receptors living in and using that environment; and the responses of the receptors to the stressors. Measurements of exposures and effects quantify the degree of interaction between these components. At a contaminated site with one stressor, the connection of the exposure and effect measurements to the assessment endpoints may be relatively simple and straightforward. In a regional multiple-stressor assessment, the number of possible interactions increases exponentially. Stressors arise from diverse sources, receptors are associated with a variety of habitats, and one impact may lead to additional direct and indirect effects (Figure 1).

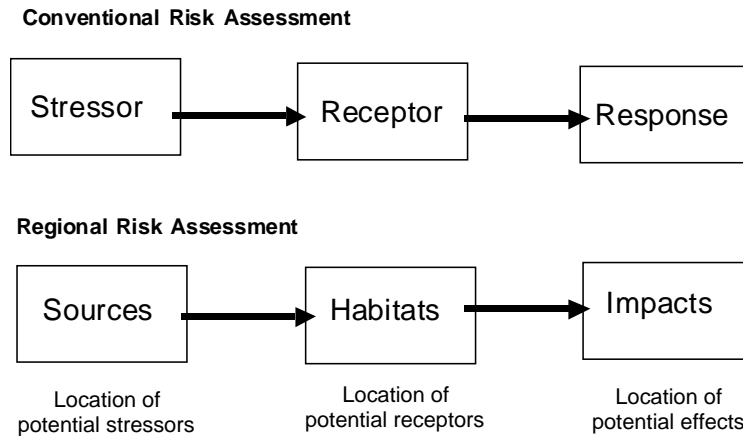


Figure 1. Comparison between conventional Ecological Risk Assessment and Regional Risk Assessment.

Risk assessment is tied directly to the construct of assessment endpoints as defined by Suter (1993). Assessment endpoints are those characteristics of the environment that are valued by society and that govern the risk decision process. Since multiple assessment endpoints are considered in a regional assessment, they are combined into an assessment volume (Landis and others 1994, Landis and McLaughlin 2000) for the risk assessment. The goal is to combine the actions of multiple stressors upon multiple assessment endpoints residing in a heterogeneous landscape.

The approach of our current regional assessment is to identify the sources and habitats in different locations (risk regions) of the Cherry Point coastal system, rank their importance in each location, and combine this information to predict relative levels of risk. The number of possible risk combinations resulting from this approach depends on the number of groups identified in each risk region. For example, if two source types and two habitat types are identified, then four possible combinations of these components can lead to an impact. If we are concerned about two different impacts, eight possible combinations exist.

Each identified combination establishes a possible pathway to a risk in that environment. If a particular combination of components affects each other, then they can be thought of as overlapping. When a source generates stressors that affect habitats important to the assessment endpoints, the ecological risk is high. A minimal interaction among components results in lower risk. If one component does not interact with one of the other two components, then no risk exists.

To understand the risk of a single impact occurring, each possible route to the impact needs investigation. However, integration of these routes is not always simple. Often, measurements of various exposure and effect levels cannot be added together to determine the overall impact to the assessment endpoint because of the different metrics used to quantify the various impacts.

Use of ranks and filters to quantify relative risk. Our regional approach incorporates a system of numerical ranks and weighting factors to address the difficulties encountered when attempting to combine different kinds of risks. Ranks and weighting factors are unit-less measures that operate under different limitations than measurements with units (e.g., mg/L, individuals/cm²). We link these ranks to specific locations within a landscape, providing a map of risks with the sources of risk clearly identified.

Spatially explicit. Sources and habitats are specifically included in the risk assessment, making it spatially explicit. Risks can be defined for specific areas, within the context of the entire region. Gradients of risk may exist, due to the presence of a variety of stressors generated by a variety of sources. The relative risks can be mapped and decisions made at a regional level.

Use in a prospective and retrospective approach. Previously published studies include examples of prospective risk assessments where future impacts are calculated. In a retrospective risk assessment the goal is to identify stressors and the sources that have contributed to an observed historical impact in that

environment. The process reverses the normal order of consideration from source-habitat-impact to impact-habitat-source.

Common ranking methodology. The numerical scores that are obtained in the ranking process are unique to the set of decisions and ranking criteria derived for that specific region. The numerical scores can not be compared directly to other studies or regions unless a set of newly derived scoring procedures are derived. If several areas are being compared in order to set remediation or management priorities, then each area needs to be combined into a single RRM setting.

Initial Cherry Point Risk Assessment

The details of the original regional risk assessment for the Cherry Point run of Pacific herring has been published (Landis and others 2000). Our original charge from the Washington State Department of Natural Resources was to evaluate the risk factors to Pacific herring posed by the Cherry Point region in order to manage the site. The next paragraphs summarize the findings of this original effort.

The region of the risk assessment is portrayed in Figure 2. Our area under consideration is from Hale Passage to Point Roberts, sites of previous spawning of the Cherry Point run of Pacific herring. The area supports a variety of land uses, from residential and manufacturing, to residential and undeveloped. Although spawning has occurred throughout the study site, it is currently limited to Point Whitehorn.

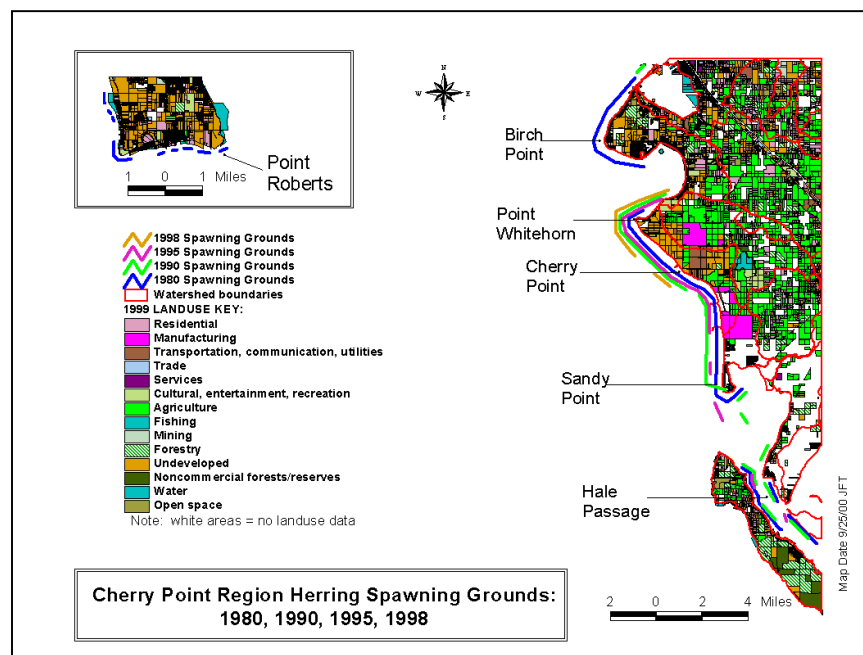


Figure 2. Map of the Cherry Point Study area including land uses and Pacific herring spawning areas.

The sources, stressors and habitat types under consideration for the initial risk assessment are listed in Table 1. These were applied to the entire Cherry Point region and to specific risk regions delineated throughout the study region. A classification scheme based upon the likelihood of effects and the uncertainty associated with each factor was developed and the risk rankings calculated.

Landis and others: *Regional Risk Assessment Predictions for Cherry Point*

Table 1. Sources, stressors and habitats of the original Cherry Point risk assessment

Sources	Stressors	Habitats
Fishing Fleets and near-shore fisheries Climate Change Industrial Sites Effluents Non-point sources from landuse Construction Hatcheries Invasive non-native species	Exploitation (Harvesting) Temperature (Pacific Decadal Oscillation) Contaminants Habitat Alteration Hatchery Fisheries Disease	Spawning and hatching area Off-shore Staging area Off-shore feeding and wintering grounds

Retrospective results for the entire Cherry Point region

The stressors and risk factors that have presented the most risk to Cherry Point herring are exploitation and loss of recruitment and/or emigration of herring from the region. Sea surface temperature changes associated with the PDO (Mantua 1997) ranked second highest for contributing to the decline in herring abundance. Other factors and stressors including habitat loss, especially around the Intalco and Tosco piers, as well as contaminants, disease, predation, and competition have contributed to a lesser degree in reducing herring numbers. However, their risks are much smaller compared to exploitation and temperature change.

Retrospective results for the risk regions

The retrospective risk regions are portrayed in Figure 3. Assessing the risks from stressors and uses within each risk region indicates there are ongoing risks to herring from many factors. When those risks are weighed in terms of causing the long-term decline of herring and elimination of all older age classes, the offshore effects of warmer climatic conditions (PDO) and exploitation could account for each effect, respectively. The offshore effects were almost uniform for each risk region, except for Alden Bank (Region 1) where the herring aggregate for several months before they move in to spawn between March and June. The aggregation of large numbers of herring in one location, over extended periods of time, places them at more risk from population-dependent stressors like disease and competition for food, as well as increases their exposure to predators and fishing.

Nearshore stressors are the second most important source of potential risk to herring, especially newly hatched larval and juvenile herring, whereas on-land uses out-rank uses related to nearshore and offshore activities. Risk regions 3 and 4 have the highest sources of potential stressors and uses to the survival of the CP herring stock. Regions 3 and 4 encompass the only area that the Cherry Point herring still use as spawning grounds in the entire region. These regions also include the BP Amoco, Intalco, and Tosco facilities, their respective piers, and ongoing shipping/cargo handling activities. These facilities and their activities pose ongoing chronic stressors to the herring and their habitat. South Lummi Bay and Hale Passage also ranked high in potential risk due to the shallowness of the area, limited vegetation for spawning habitat, strong currents, and tremendous recreational sailing, boating and fishing activities within a constrained area.

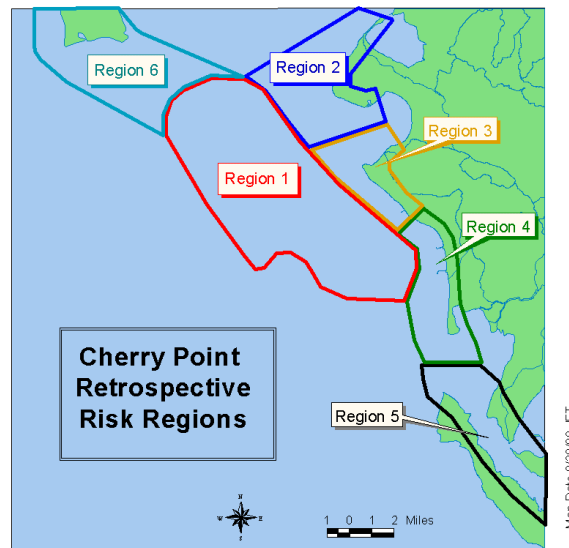


Figure 3: Cherry Point Retrospective Risk Regions

The final step in the retrospective assessment was to add the final risk scores for sources and uses in each of the risk regions. Combining the sources and uses together enables an overall assessment of the adverse impacts in each of the risk regions. Alden Bank ranks highest, with all the other risk regions being at medium-high risk.

Prospective results for the risk regions

In conducting the prospective analysis of each of the risk regions we assumed that there would be a cessation of fishing for herring and harvesting of roe for at least 6 to 10 years. We also assumed that each risk region would be exposed to the same stressors and uses with the same high probability that there would be an effect associated with the exposure.

The highest source of risk from offshore to herring will be climatic changes, specifically a warm PDO event. Recent studies indicate that the warm PDO event that began in 1977 may have come to an end in 1998. The weather in the next year or so should confirm these preliminary indications. If the Pacific northwest is entering into a cool PDO event lasting 20 to 30 years, then in combination with the cessation of fishing, Cherry Point herring abundances should begin to increase in the next few years.

Nearshore and on-land uses will determine the quantity and duration of future stressors to the CP herring. Continued development in the CP vicinity including agriculture, industry and more specifically increased cargo and bulk shipping to the piers will increase the potential risk to the remaining herring that are spawning there currently. Any uses occurring on land or in the nearshore areas of risk regions 2, 3, and 4 will potentially have some effect on herring. However, the level of risk can be mediated by; best management practices, good planning, reducing waste stream concentrations, and collaborative partnerships between the area's stakeholders, with guidance from the appropriate state agencies.

Characterizing and Modeling the Cherry Point Herring Stock

A data analysis and modeling effort was undertaken to better characterize the Pacific herring spawning at Cherry Point. The population dynamics from 1974 to 1998 were reconstructed using the EVS (1999) compilations of numbers of fish at each age for each year. Survivorship rates between age classes was estimated for each year.

Population Trends

Two clear trends appear from the plotting of the numbers of adult fish since the early 1970s. First is a general decline in the population although the numbers of fish fluctuate wildly (Figure 4a). The important signal is not in the general but erratic decline of the population but is in the change of the age structure of the population during the same period. Figure 4b compares the number of Age 2 and 3 fish to those Age 4 and greater. The number of fish Age 4 and older exhibits a steady decline while the number of younger fish increases and then fluctuates without an apparent trend until after 1995. In 1998 Age 4 and older fish are essentially extinct and the Age 2 and 3 fish are at low numbers. Clearly, there are impacts that differentially reduce the older age classes during the late 1970s until the late 1990s for the Cherry Point Herring.

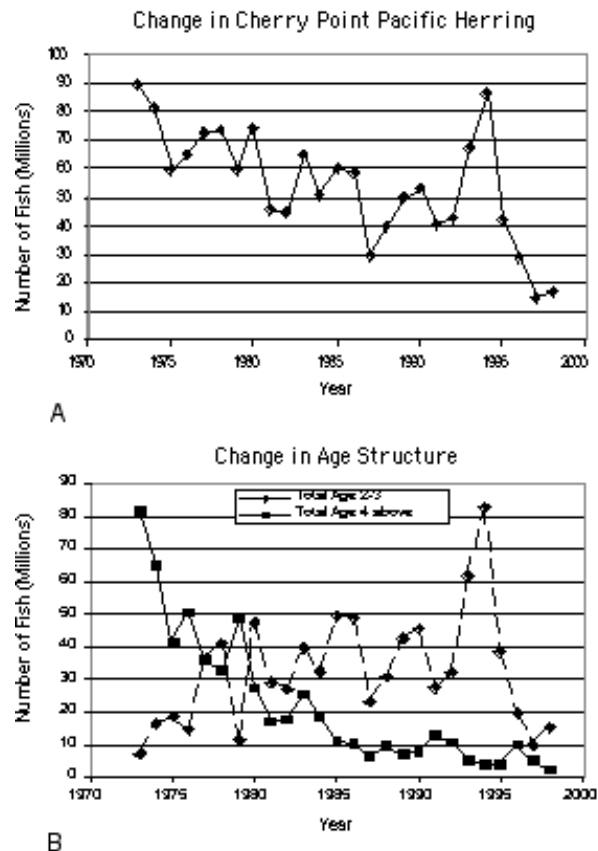


Figure 4. Population Dynamics of the Cherry Point Pacific herring.

Fecundity and Survivorship Trends

A critical component of attempting to reconstruct survivorship from egg to Age 2 and for predictions of future population dynamics is an estimate of fecundity within the population. Age specific fecundity estimates were based on a report for Puget Sound Pacific herring (Chapman and others 1941) that counted eggs per female for fish from Age 2 to Age 8. A regression was used to fit a line to describe the relationship between age and fecundity with the equation of $F = -2125 + 5419 A$ where F is number of eggs per individual and A is the age of the fish. The regression was significant ($p < 0.05$) with an R^2 of 0.77.

Puget Sound Research 2001

Residuals were plotted and no apparent pattern of bias was observed.

Survivorship from egg to Age 2 was estimated by comparing the number of estimated two-year olds to the number of eggs estimated for the appropriate year. No sex ratios for the Cherry Point herring for each year have been found so the number in the plots assume that the entire population was female. The survivorship was plotted by year. Assuming a 50:50 distribution of male and female will double the survivorship estimates used in the plots, but the trends will remain the same.

The overall fertility of the population steadily dropped during the period under consideration (Figure 5a). This trend reflects the decrease in the number of fish in the Age 4 and older age classes that have a markedly higher individual fecundity. Loss of the older and larger fish rapidly decreases the overall fecundity of the population.

Although the number of eggs decreased, survivorship from egg to Age 2 did not show a similar trend (Figure 5b). During the late 1970s to the end of the study period the survivorship was greater than in the early 1970s. In some years there is a marked increase in calculated survivability corresponding to an increase in the early age classes. This trend counters the suggestion that there has been an increase in egg to Age 2 mortality corresponding to the decrease in Cherry Point Pacific herring.

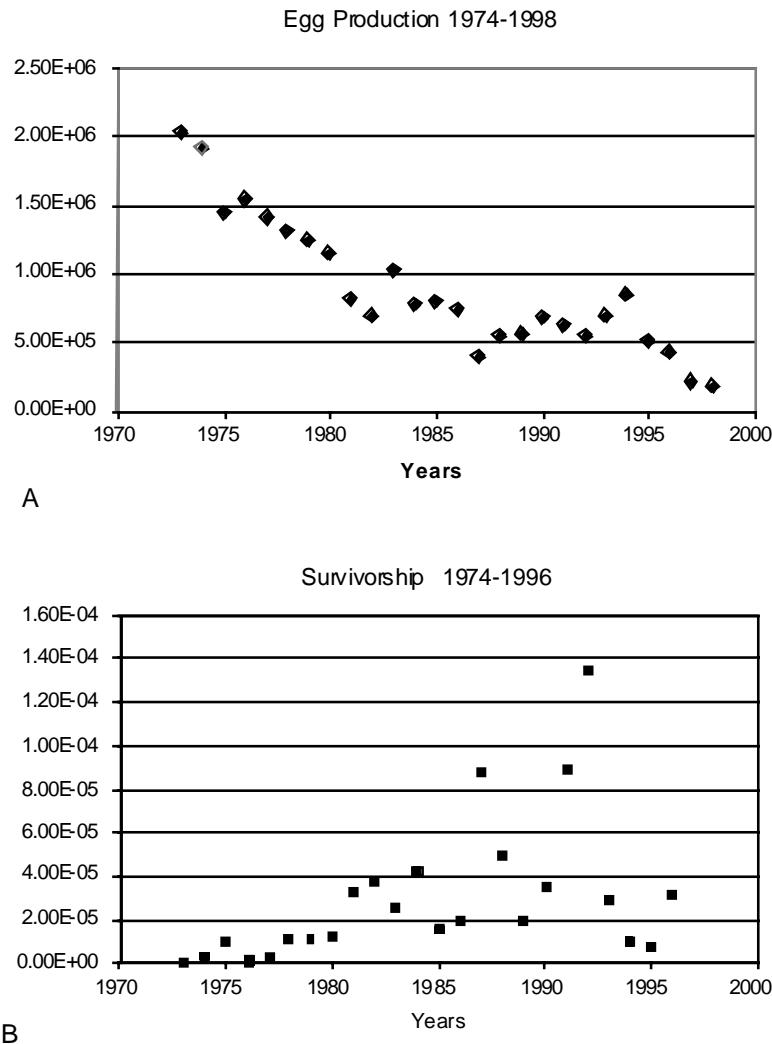


Figure 5. Egg production and egg to Age 2 survivorship for Cherry Point Pacific herring.

Prospective Population Modeling

We used modeling to estimate the necessary range of conditions to produce an increase in the number of Cherry Point Pacific herring. Estimates of future population dynamics was conducted by reconstructing a life history table comprising the age specific survivorship to the next age class, and the fecundity for each age class for Age 2 to Age 9. The total number of eggs produced was multiplied by the survivorship quotient from egg to Age 2 for the recruitment of the Age 2 class for each year. The survivorship quotient for 1990 was used for each simulation. It was assumed that the population each year had a sex ratio of 50:50. In the simulations the initial populations were from either 1998 or 1983. Simulations were conducted with a constant age-specific survivorship from each of the years 1974 to 1998 to explore the range of possible outcomes over a 15 year period. No density dependence was assumed in the survivorship of the eggs to Age 2 or in the fecundity of the population.

Positive population growth was calculated using the survivorship tables for all the years 1974 to 1985 and then 1988 and then 1981. All other years resulted in a long-term decreasing trend in the overall population size. There appears to be two key factors in the patterns of long-term increases in the fish populations. First is the survivorship of the older age classes. In each instance where the population demonstrated a steady increase there was an increase in the number of fish Age 4 and older. The other factor was apparent migration into the population from other sources. In the early 1970s to the mid-1980s there was an apparent

greater increase in the Age 3 or Age 4 class than could be accounted for from the numbers of the earlier age class the year before. Although the increase may be the result of sampling error, the increases were occasionally 30-70 times the expected number. This suggests that at one time there was immigration into the Cherry Point Pacific herring Population that corresponded to periods of high population numbers. If immigration is important to the understanding of the long-term population dynamics of the Pacific herring at Cherry Point then it is critical to understand the relationships among the various spawning populations in the Georgia Straits.

Our next modeling efforts will to attempt to simulate the variability of the population dynamics of the Cherry Point Pacific herring by allowing the age-specific survivorship to vary randomly between the range found in the existing datasets. Trends will also be sought for relationships between sea-surface temperature or other factors, especially in the constant decline of the Age 4 and older fish.

Comparisons to other Puget Sound Pacific herring Stocks

It is potentially useful to compare the population structure of the Cherry Point Pacific herring to other spawning runs in Puget Sound. In this comparison we use the 2000 census data kindly supplied by M. O'Toole of the Washington State Department of Fish and Wildlife. The estimates are in biomass (tons) as obtained by deposition surveys or acoustic trawls.

The comparison of the age structures from the 10 runs for which data are available clearly demonstrates the compression of the age structure is common to all (Figure 6). No population has a fish Age 6 or older. In six of the runs the dominant Age is 2, with Age 3 in the remaining populations. Only Cherry Point and Port Susan have a fraction of Age 4 fish in the population that exceeds 20%. Although the current age distribution of spawning herring at Cherry Point is very different from that of the 1970s and 1980s, it is similar to contemporary Puget Sound populations.

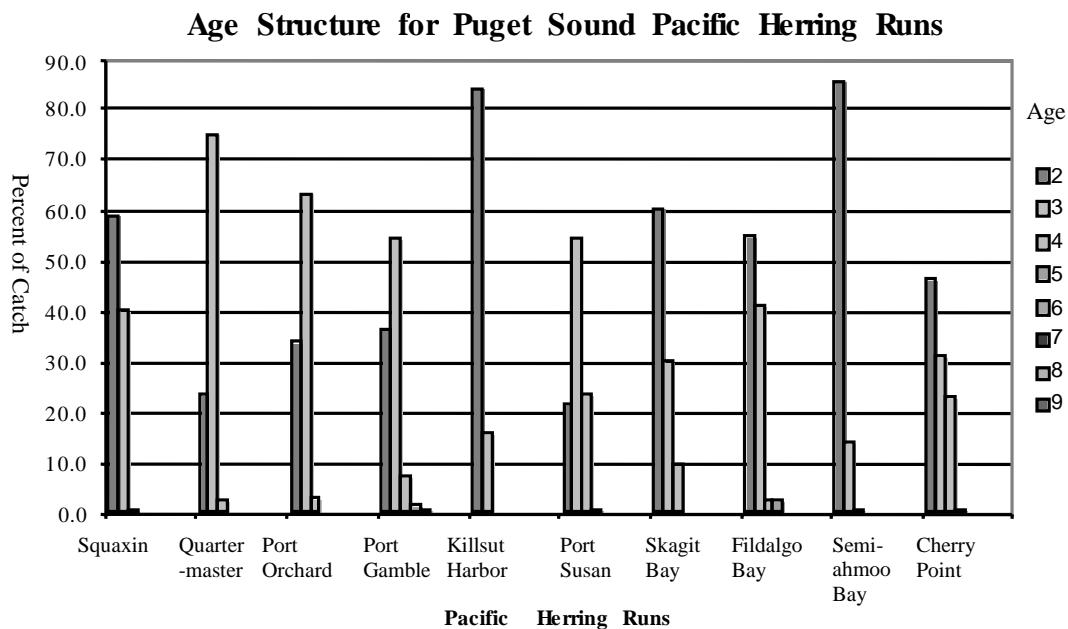


Figure 6. Comparison of the age structures of Puget Sound runs of Pacific herring.

In order to compare the contribution of the population size (biomass) and structure to outside factors in controlling the size of the population in succeeding generations a scatterplot was graphed between population size at year N and the population at year N+1 for the runs with sufficient data. Observation of each graph showed a great deal of scatter for each run. A linear regression was performed for each data set. The results are presented in Table 2. Five runs exhibited significant relationships between the population at

time N and the population size and time N+1, Quatermaster Harbor, Point Orchard, Fildago Bay, Cherry Point and Discovery Bay. The R^2 in most cases was very low even for those sites with statistically significant relationships, indicating that a variety of other factors other than age-structure are contributing to the population size in these regions.

Re-evaluating the risk assessment

The original RRM was re-evaluated using the population data gathered since the original risk assessment and the inclusion of a Valdez style scoring scheme. The goal of this re-evaluation was to examine the robustness of the original evaluation using different scoring schemes to ensure that the incorporation of uncertainty in the initial analysis did not bias the results. An additional source was also included, exposure to contaminants outside of the Cherry Point region during the migration of the Pacific herring during the part of the year not associated with spawning.

Table 2. Regression results for the phase plots for Puget Sound Pacific herring.

Site	Significance	R^2
Quatermaster	*	0.40
Point Orchard	*	0.30
Port Gamble		0.10
Port Susan		0.14
Fildago Bay	*	0.51
Samish, Portage Bay		0.11
Semiahmoo Bay		0.16
Cherry Point	*	0.64
Discovery Bay	*	0.76

An alternative scoring scheme was established modeled closely on the Valdez-style inputs that did not incorporate uncertainty into the scoring scheme. In the revised scheme uncertainty is treated separately in the analysis making the evaluation much more explicit. The relative risk to the entire region was calculated and was not broken down to risk regions.

The conclusions of the original risk assessment largely were confirmed. Climate change as manifested by the PDO and exploitation ranked as the highest risks and had a relatively low uncertainty. It is clear that both events have occurred and both have potentially devastating impacts upon herring populations.

Contamination derived from outside the study area did rank as a high risk, but the uncertainty associated with this source is very high. Little documentation of concentration of important contaminants in the free ranging herring population is available. Although potentially important, it is not clear what the exposure to the herring during the years and nor what types of contaminants. Unless sufficient sampling and analytical chemistry is performed to document exposure, this potential source will have an associated high uncertainty.

Impacts due to disease and hatchery fish have a low risk and have an associated large uncertainty.

Alternative Species of Concern

Pacific herring are transitory and spend only a brief part of their life history in the Cherry Point region. The Regional Risk Assessment for the Cherry Point Herring Stock (Landis and others 2000) illustrated that the Cherry Point Pacific herring are impacted primarily by large scale events and other factors in Puget Sound and the Georgia Straits, not by local effects specific to Cherry Point. It is important to find resident organisms that can provide more reliable indicators of the impacts and changes to the Cherry Point region.

Puget Sound Research 2001

Ecological management of the Cherry Point Reserve requires information specific to Cherry Point and the organisms living there. We have identified several species other than Pacific herring as candidates for further investigation in the Cherry Point region. The species were chosen because they exhibited one or more of the following characteristics:

- Utilizes habitat with a high probability of exposure to contaminants.
- Is a resident of the region year-round.
- Is commercially important.
- Is ecologically connected to the Pacific herring.
- Plays a similar role as Pacific herring in trophic structure.

Species with these characteristics will provide useful information about the potential impacts from sources of stressors specific to the Cherry Point region. Information about the potential impacts to these species and the interactions between them will facilitate the ecological management of the Cherry Point Reserve.

Eelgrass (*Zostera marina*) and Marine Macro-algae:

Reason for Selection: Provides valuable habitat to a variety of nearshore species including Pacific herring and Dungeness crab.

Possible measurement endpoints: Presence/absence, density, uptake rates of environmental pollutants including metals and hydrocarbons.

Surf smelt (*Hypomesus pretiosus*) and Sand lance (*Ammodytes hexapterus*):

Reason for Selection: Forage fishes. Utilize sand and gravel beaches for spawning habitat. Because many toxicants are lipophilic, they are more likely to be found in the sand and sediments than in the water column. For this reason, surf smelt and sand lance eggs have a high probability of exposure, and therefore effects, if toxicants are present in the Cherry Point region.

Possible Measurement Endpoints: Presence/absence, tissue contaminant concentrations, acute toxicity testing of sand/sediments on eggs and larvae, relative mortality rates and number of deformities of eggs/larvae. Sand/sediments can be analyzed for the presence of toxicants to assess the possibility of exposure.

Dungeness Crab (*Cancer magister*):

Reason for Selection: Commercially important, utilize sediment as habitat—able to bioaccumulate toxic substances from environment, reside in region year-round.

Possible Measurement Endpoints: Distribution, fecundity, size, sediment toxicity, tissue contaminant concentrations, and biomarker enzyme concentrations.

Shellfish:

Reason for Selection: Preyed upon by Dungeness crab, commercially important, utilize sediment as habitat—able to bioaccumulate toxic substances from environment, previously used as to test toxicity.

Possible Measurement Endpoints: Distribution, fecundity, size, sediment toxicity, tissue contaminant concentrations, and biomarker enzyme concentrations.

Great Blue Heron (*Ardea herodias*):

Reason for Selection: Utilizes both terrestrial and aquatic habitat. Preys upon forage fish (such as Pacific herring, surf smelt and sand lance) and terrestrial rodents.

Possible Measurement Endpoints: Distribution, fecundity, tissue contaminant concentrations, and biomarker enzyme concentrations.

Other species were also considered as candidate alternative endpoints but were not included in these recommendations for several reasons. Specifically, a member of the salmonid species was considered but soon rejected as a plausible alternative endpoint species for several reasons: First, like herring, salmon also are transitory in nature. They spend only a small part of their lifetimes in the nearshore environs. Second, because of the ESA listing of several salmonid species, a large amount of resources is already dedicated to

study and monitor these species. Including salmonids as a component in the Cherry Point risk assessment is not appropriate for these reasons.

The most critical to monitor

If limited financial resources reduce the number of species WDNR is able to include in further Cherry Point studies, the following species will provide the most valuable information about the Reserve. These include eelgrass, surf smelt, Dungeness crab and great blue heron. While the including shellfish will provide the most complete evaluation of the Cherry Point Reserve, this short list covers the most important links, including; the base of the detritus-based food web, an organism residing in/near the sediment where exposure to lipophilic toxicants is most likely, a resident forage fish, and a nearshore bird species that utilizes both the terrestrial and the aquatic environments. The uncertainty analysis in the multiple-species risk assessment of the Cherry Point region (being conducted by Emily Hart Hayes for a WWU master's thesis in 2001-2002) will also provide more information regarding the most critical species to monitor.

Conclusions and Recommendations

The decline in the CP herring is likely tied to large-scale stressors that appear to be working within all of Puget Sound. The general decline in population size, compression of the age structure, and the erratic nature of the population dynamics are traits that all of the Puget Sound Pacific herring runs have in common. The broad geographical nature of these characteristics points to sources of stressors working at comparable scales. These stressors include harvesting, climate change, and a region-wide source of contaminants.

There is an overwhelming need to understand the loss of the older age classes within the herring population. Although the decline of the herring population has affected all age classes, it is the loss of the older age classes that is characteristic of both Cherry Point and other runs of Pacific herring. The most profound difference between the Pacific herring at Cherry Point between the 1970s and now is the elimination of detectable Age 5 and older herring when the former life expectancy was up to 9 years. Given the greater reproductive output of these older and larger fish, these age classes are key to establishing sustainable populations of herring in the region.

It is absolutely necessary to understand the contaminant loading in adult fish before spawning and in the eggs. Contaminants could be an important risk factor, especially those that the Pacific herring are exposed to in the time spent away from the spawning areas. Measurements need to be taken on adult fish as they congregate prior to spawning, and also after post-spawn to estimate depuration to the eggs. Substituted halogenated and polyaromatic organic contaminants may be important, but metals cannot be overlooked. Only when the exposure to contaminants is characterized can the uncertainty associated with contaminants as a stressor be reduced.

Because of the wide range of the adults and the predominant influence of stressors outside Cherry Point, herring are a poor measure of the ecological status of the Cherry Point area. The goal of the risk assessment effort has been to aid the decision making process for the management of the natural resources within the Cherry Point region. Basing the decision upon a species that is transitory to the region and sensitive to large scale influences will not provide timely information upon impacts and improvements to the natural resources of the region.

Alternative indicators are presented that should provide more reliable tools for the management of the resources specific to the Cherry Point area. Not only are many of these indicators important on their own merits, but they also will provide information on the status of the region for providing a variety of natural resources. Because of the resident nature of most of these endpoints the information they provide should be timely and geographically explicit.

Finally, these alternative endpoints, especially the eelgrass, will provide important information upon the suitability of the Cherry Point region as spawning grounds for Pacific herring. As the warm PDO reverses to cooler temperatures and exploitation is properly regulated, it is expected that the spawning population in the area should increase. Only if suitable habitat is preserved can the large runs of the 1970s be revisited.

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References

- Chapman, W. M., M. Katz and D. W. Erickson. 1941. *The Races of Herring in the State of Washington. Biological Report No. 38A*. Department of Fisheries State of Washington.
- EVS Environmental Consultants. 1999. *Cherry Point Screening Level Ecological Risk Assessment*. Prepared for the Washington Department of Natural Resources. EVS Project No. 2/868-01.1. EVS Environmental Consultants, Seattle, WA. 465pp.
- Landis, W. G., G. B. Matthews, R. A. Matthews, and A. Sergeant. 1994. Application of multivariate techniques to endpoint determination, selection and evaluation in ecological risk assessment. *Environ. Toxicol. Chem.* 12: 1917-1927
- Landis, W. G. and J. A. Wiegiers. 1997. Design considerations and a suggested approach for regional and comparative ecological risk assessment. *Human and Ecological Risk Assessment*. 3:287-297.
- Landis, W. G. and J. F. McLaughlin. 2000. Design criteria and derivation of indicators for ecological position, direction and risk. *Environ. Toxicol. Chem.* 19:1059-1065.
- Landis W. G., A. J. Markiewicz, J. Thomas and P. B. Duncan. 2000. *Regional Risk Assessment for the Cherry Point Herring Stock*. Western Washington University Technical Report October 13, 2000.
- Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society*, 78:1069-1079.
- Suter, G. W. II. 1993. Regional Risk Assessment. In *Ecological Risk Assessment*. Lewis Publishers, Chelsea, MI. pp. 365-376.
- Wiegiers, J. K., H. M. Feder, L. S. Mortensen, D. G. Shaw, V. J. Wilson and W. G. Landis. 1998. A regional multiple stressor rank-based ecological risk assessment for the fjord of Port Valdez, AK. *Human and Ecological Risk Assessment* 4:1125-1173.